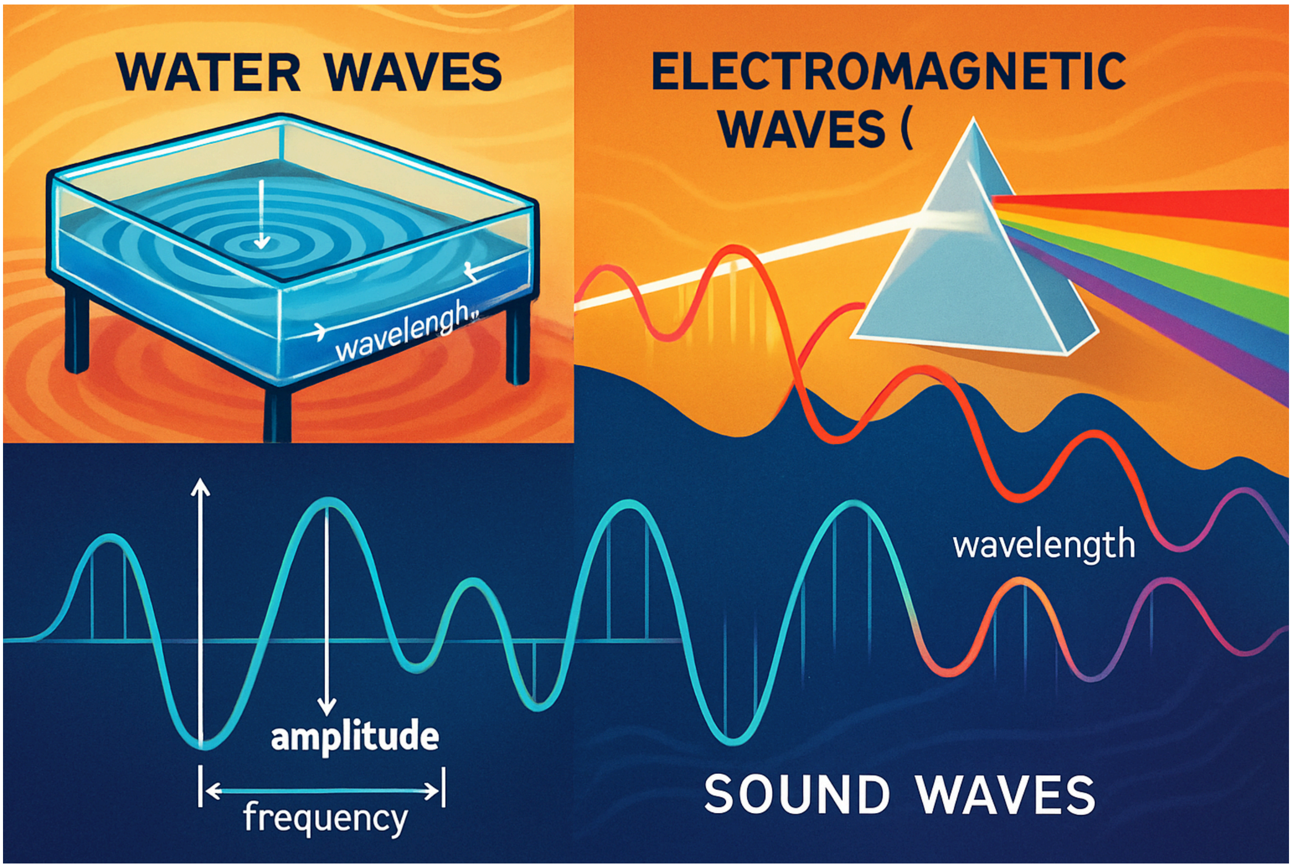
IGCSE Physics: Waves

Syllabus Code: 0625



Learning Objectives

3.1 General properties of waves

- Know that waves transfer energy without transferring matter
- Describe what is meant by wave motion as illustrated by vibrations in ropes and springs, and by experiments using water waves
- Describe the features of a wave in terms of wavefront, wavelength, frequency, crest (peak), trough, amplitude and wave speed
- Recall and use the equation for wave speed $v = f\lambda$

- Know that for a transverse wave, the direction of vibration is at right angles to the direction of propagation and understand that electromagnetic radiation, water waves and seismic S-waves (secondary) can be modelled as transverse
- Know that for a longitudinal wave, the direction of vibration is parallel to the direction of propagation and understand that sound waves and seismic P-waves (primary) can be modelled as longitudinal
- Describe how waves can undergo: (a) reflection at a plane surface, (b) refraction due to a change of speed, (c) diffraction through a narrow gap
- Describe how wavelength and gap size affects diffraction through a gap
- Describe the use of a ripple tank to show: (a) reflection at a plane surface, (b) refraction due to a change in speed caused by a change in depth, (c) diffraction due to a gap, (d) diffraction due to an edge
- Describe how wavelength affects diffraction at an edge

3.2 Light

3.2.1 Reflection of light

- Define and use the terms normal, angle of incidence and angle of reflection
- Describe the formation of an optical image by a plane mirror and give its characteristics, i.e. same size, same distance from mirror, virtual
- State that for reflection, the angle of incidence is equal to the angle of reflection; recall and use this relationship
- Use simple constructions, measurements and calculations for reflection by plane mirrors

3.2.2 Refraction of light

- Define and use the terms normal, angle of incidence and angle of refraction
- Describe an experiment to show refraction of light by transparent blocks of different shapes
- Define refractive index, n, as the ratio of the speeds of a wave in two different regions
- Describe the passage of light through a transparent material (limited to the boundaries between two mediums only)

- Recall and use the equation n = sin i / sin r
- State the meaning of critical angle
- Recall and use the equation n = 1 / sin c
- Describe internal reflection and total internal reflection using both experimental and everyday examples
- Describe the use of optical fibres, particularly in telecommunications

3.2.3 Thin lenses

- Describe the action of thin converging and thin diverging lenses on a parallel beam of light
- Define and use the terms focal length, principal axis and principal focus (focal point)
- Draw and use ray diagrams for the formation of a real image by a converging lens
- Draw and use ray diagrams for the formation of a virtual image by a converging lens
- Describe the characteristics of an image using the terms enlarged/same size/diminished, upright/inverted and real/virtual
- Describe the use of a single lens as a magnifying glass
- Know that a virtual image is formed when diverging rays are extrapolated backwards and does not form a visible projection on a screen
- Describe the use of converging and diverging lenses to correct long-sightedness and short-sightedness

3.2.4 Dispersion of light

- Describe the dispersion of light as illustrated by the refraction of white light by a glass prism
- Know the traditional seven colours of the visible spectrum in order of frequency and in order of wavelength
- Recall that visible light of a single frequency is described as monochromatic

3.3 Electromagnetic spectrum

- Know the main regions of the electromagnetic spectrum in order of frequency and in order of wavelength
- Know that all electromagnetic waves travel at the same high speed in a vacuum
- Know that the speed of electromagnetic waves in a vacuum is 3.0×10^8 m / s and is approximately the same in air
- Describe typical uses of the different regions of the electromagnetic spectrum including: (a) radio waves; radio and television transmissions, astronomy, radio frequency identification (RFID), (b) microwaves; satellite television, mobile phones (cell phones), microwave ovens, (c) infrared; electric grills, short range communications such as remote controllers for televisions, intruder alarms, thermal imaging, optical fibres, (d) visible light; vision, photography, illumination, (e) ultraviolet; security marking, detecting fake bank notes, sterilising water, (f) X-rays; medical scanning, security scanners, (g) gamma rays; sterilising food and medical equipment, detection of cancer and its treatment
- Describe the harmful effects on people of excessive exposure to electromagnetic radiation, including: (a) microwaves; internal heating of body cells, (b) infrared; skin burns, (c) ultraviolet; damage to surface cells and eyes, leading to skin cancer and eye conditions, (d) X-rays and gamma rays; mutation or damage to cells in the body
- Know that communication with artificial satellites is mainly by microwaves
- Know that many important systems of communications rely on electromagnetic radiation including: (a) mobile phones (cell phones) and wireless internet use microwaves because microwaves can penetrate some walls and only require a short aerial for transmission and reception, (b) Bluetooth uses radio waves because radio waves pass through walls but the signal is weakened on doing so, (c) optical fibres (visible light or infrared) are used for cable television and high-speed broadband because glass is transparent to visible light and some infrared; visible light and short wavelength infrared can carry high rates of data
- Know the difference between a digital and analogue signal
- Know that a sound can be transmitted as a digital or analogue signal
- Explain the benefits of digital signalling including increased rate of transmission of data and increased range due to accurate signal regeneration

3.4 Sound

- Describe the production of sound by vibrating sources
- Describe the longitudinal nature of sound waves
- Describe compression and rarefaction
- State the approximate range of frequencies audible to humans as 20 Hz to 20 000 Hz
- Know that a medium is needed to transmit sound waves
- Know that the speed of sound in air is approximately 330–350 m / s
- Know that, in general, sound travels faster in solids than in liquids and faster in liquids than in gases
- Describe a method involving a measurement of distance and time for determining the speed of sound in air
- Describe how changes in amplitude and frequency affect the loudness and pitch of sound waves
- Describe an echo as the reflection of sound waves
- Define ultrasound as sound with a frequency higher than 20 kHz
- Describe the uses of ultrasound in non-destructive testing of materials, medical scanning of soft tissue and sonar including calculation of depth or distance from time and wave speed

Core Content

3.1 General properties of waves

Wave Motion

Waves are disturbances that transfer energy from one place to another without transferring matter. This can be visualized with ropes, springs, or water waves. In a rope, a flick of the wrist creates a wave that travels along the rope, but the rope itself does not move forward.

Features of a Wave

- **Wavefront:** An imaginary line connecting points on a wave that are in the same phase (e.g., all crests).
- **Wavelength (λ):** The distance between two consecutive crests or troughs.
- **Frequency (f):** The number of complete waves passing a point per second, measured in Hertz (Hz).
- **Crest (Peak):** The highest point of a wave.
- **Trough:** The lowest point of a wave.
- **Amplitude:** The maximum displacement of a particle from its equilibrium position.
- **Wave Speed (v):** The speed at which the wave travels.

Wave Equation

The relationship between wave speed, frequency, and wavelength is given by the wave equation:

Formula: $v = f\lambda$

Types of Waves

- **Transverse Waves:** The vibrations are perpendicular to the direction of energy transfer. Examples include light, all electromagnetic waves, water waves, and seismic S-waves.
- **Longitudinal Waves:** The vibrations are parallel to the direction of energy transfer. They consist of compressions (regions of high pressure) and rarefactions (regions of low pressure). Examples include sound waves and seismic P-waves.

Wave Phenomena

- **Reflection:** The bouncing back of a wave when it hits a surface. The angle of incidence equals the angle of reflection.
- **Refraction:** The bending of a wave as it passes from one medium to another, caused by a change in speed.
- **Diffraction:** The spreading out of a wave as it passes through a gap or around an obstacle. Diffraction is most significant when the gap size is similar to the wavelength of the wave.

Ripple Tank

A ripple tank is a shallow glass-bottomed tank of water used to demonstrate wave phenomena like reflection, refraction, and diffraction.

3.2 Light

Reflection of Light

When light hits a plane mirror, it reflects. The **normal** is a line perpendicular to the mirror surface at the point of incidence. The **angle of incidence (i)** is the angle between the incident ray and the normal, and the **angle of reflection (r)** is the angle between the reflected ray and the normal. The law of reflection states that **angle of incidence = angle of reflection (i = r)**.

An image formed by a plane mirror is: * **Virtual:** It cannot be projected onto a screen. * **Upright:** The same way up as the object. * **Laterally inverted:** Left and right are swapped. * **Same size** as the object. * **Same distance** behind the mirror as the object is in front.

Refraction of Light

Refraction is the bending of light as it passes from one medium to another (e.g., from air to glass). This happens because light travels at different speeds in different media. The **refractive index (n)** of a medium is a measure of how much it slows down light.

Formulas: * $n = speed\ of\ light\ in\ vacuum / speed\ of\ light\ in\ medium$ * **Snell's Law:** $n = sin(i)/sin(r)$

Total Internal Reflection (TIR)

When light travels from a denser medium to a less dense medium (e.g., from glass to air), it bends away from the normal. If the angle of incidence is increased, the angle of refraction also increases. At a certain angle of incidence, called the **critical angle (c)**, the angle of refraction is 90°. If the angle of incidence is greater than the critical angle, the light is totally internally reflected.

Formula: $n = 1/sin(c)$

Optical Fibres

Optical fibres use total internal reflection to transmit light over long distances with minimal loss of signal. They are used in telecommunications for high-speed internet and cable TV.

Thin Lenses

- **Converging Lens (Convex):** A lens that brings parallel rays of light to a focus at the **principal focus (focal point)**. It can form both real and virtual images.
- **Diverging Lens (Concave):** A lens that spreads out parallel rays of light. It always forms a virtual, diminished, and upright image.

Ray Diagrams

Ray diagrams can be used to determine the position and nature of an image formed by a lens. A **real image** is formed where rays of light actually converge, and it can be projected onto a screen. A **virtual image** is formed where rays of light appear to diverge from, and it cannot be projected.

Uses of Lenses

- **Magnifying glass:** A converging lens used to produce a magnified virtual image.
- **Correcting vision:** Converging lenses are used to correct long-sightedness (hyperopia), and diverging lenses are used to correct short-sightedness (myopia).

Dispersion of Light

Dispersion is the splitting of white light into its constituent colours (the visible spectrum) when it passes through a prism. This happens because each colour has a different wavelength and is refracted by a different amount. The order of colours is Red, Orange, Yellow, Green, Blue, Indigo, Violet (ROYGBIV), with red having the longest wavelength and being refracted the least, and violet having the shortest wavelength and being refracted the most.

3.3 Electromagnetic spectrum

The electromagnetic (EM) spectrum is a continuous range of electromagnetic waves, ordered by frequency and wavelength. All EM waves are transverse waves that travel at the speed of light in a vacuum (approximately 3.0×10^8 m/s).

Regions of the EM Spectrum (in order of increasing frequency/decreasing wavelength):

Radio waves → Microwaves → Infrared → Visible light → Ultraviolet → X-rays → Gamma rays

Uses and Dangers of EM Waves

Region	Uses	Dangers
Radio waves	Radio/TV, astronomy, RFID	None known
Microwaves	Satellite TV, mobile phones, microwave ovens	Internal heating of body cells
Infrared	Grills, remote controls, intruder alarms, thermal imaging, optical fibres	Skin burns
Visible light	Vision, photography, illumination	Damage to eyes (if too bright)
Ultraviolet	Security marking, detecting fake notes, sterilising water	Skin cancer, eye damage
X-rays	Medical scanning, security scanners	Cell damage, mutations
Gamma rays	Sterilising food/equipment, cancer treatment/detection	Cell damage, mutations

Communications

- **Microwaves** are used for satellite and mobile phone communication.
- **Radio waves** are used for Bluetooth.
- **Visible light and infrared** are used in optical fibres for high-speed data transmission.

Analogue vs. Digital Signals

- **Analogue signals** are continuous and vary smoothly.
- **Digital signals** are discrete and consist of a series of on/off pulses (1s and 0s).

Digital signals are preferred for communication because they are less prone to noise, can be regenerated perfectly, and allow for a higher rate of data transmission.

3.4 Sound

Production and Nature of Sound

Sound is produced by vibrating sources. It is a longitudinal wave that requires a medium (solid, liquid, or gas) to travel. Sound waves consist of compressions (regions of high pressure) and rarefactions (regions of low pressure).

Properties of Sound

- **Audible Range:** The range of frequencies humans can hear is approximately 20 Hz to 20,000 Hz.
- **Speed of Sound:** The speed of sound in air is approximately 330–350 m/s. Sound travels fastest in solids, slower in liquids, and slowest in gases.
- **Loudness and Pitch:** The loudness of a sound is determined by its amplitude, and the pitch is determined by its frequency.
- **Echo:** An echo is a reflection of a sound wave.
- **Ultrasound:** Sound with a frequency above 20,000 Hz, which is inaudible to humans.

Uses of Ultrasound

- **Non-destructive testing:** Detecting flaws in materials.
- **Medical scanning:** Creating images of soft tissues and organs (e.g., prenatal scans).
- **Sonar:** Used by ships and submarines to determine the depth of the sea or locate underwater objects.

Key Terms & Definitions

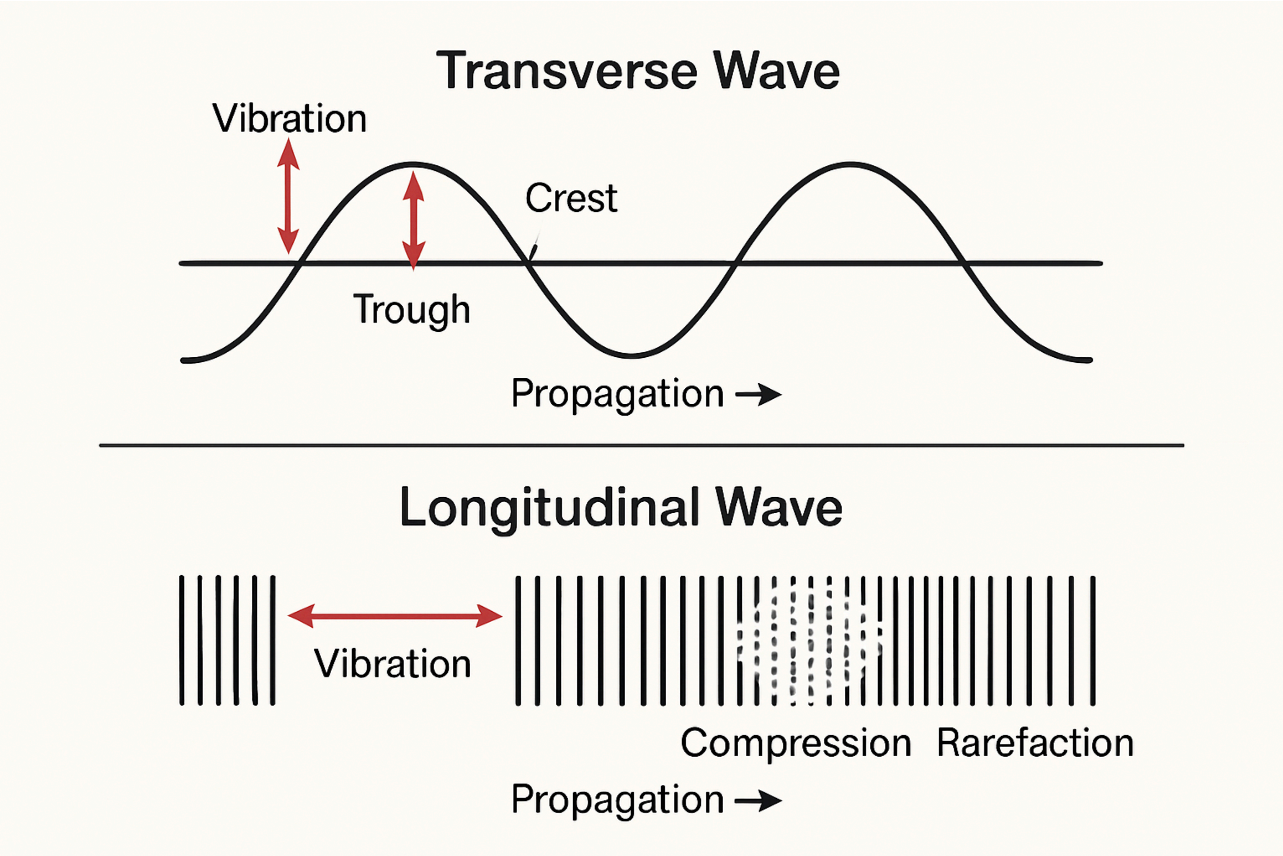
Term	Definition
Wave	A disturbance that transfers energy without transferring matter.
Transverse Wave	A wave in which the vibrations are perpendicular to the direction of energy transfer.
Longitudinal Wave	A wave in which the vibrations are parallel to the direction of energy transfer.
Reflection	The bouncing back of a wave from a surface.
Refraction	The bending of a wave as it passes from one medium to another.
Diffraction	The spreading out of a wave as it passes through a gap or around an obstacle.
Refractive Index	A measure of how much a medium slows down light.
Total Internal Reflection	The complete reflection of a light ray back into its original medium when the angle of incidence is greater than the critical angle.
Dispersion	The splitting of white light into its constituent colours.
Electromagnetic Spectrum	The range of all types of electromagnetic radiation.
Sound	A longitudinal wave produced by vibrating sources.
Ultrasound	Sound with a frequency above the range of human hearing.

Summary & Review

This study guide covered the properties and phenomena of waves. We distinguished between transverse and longitudinal waves, and explored reflection, refraction, and diffraction. We then focused on light, covering reflection, refraction, total internal reflection, lenses, and dispersion. The electromagnetic spectrum was examined in terms of its regions, uses, and dangers, along with the principles of analogue and digital communication. Finally, we studied sound waves, their properties, and the applications of ultrasound.

Further Reading

- [Save My Exams: IGCSE Physics - Waves]
- [Physics & Maths Tutor: IGCSE Physics Notes]
- [Khan Academy Physics]



3.1 General properties of waves (continued)

Diffraction at an Edge

When waves pass an edge, they spread out into the region behind the edge. The extent of this spreading (diffraction) depends on the wavelength of the wave. Longer wavelengths diffract more significantly than shorter wavelengths when passing the same edge.

3.2 Light (continued)

Optical Fibres and Telecommunications

Optical fibres are thin strands of glass or plastic used to transmit light signals over long distances. Their operation relies on the principle of **total internal reflection**. Light signals entering the fibre at a sufficiently large angle are repeatedly reflected off the inner walls of the fibre, allowing them to travel great distances with minimal loss. This property makes them ideal for telecommunications, enabling high-speed internet, telephone, and cable television services.

3.3 Electromagnetic spectrum (continued)

Satellite Communication

Many important communication systems rely on electromagnetic radiation, particularly microwaves, for satellite communication:

- **Low Orbit Artificial Satellites:** Some satellite phones use low Earth orbit (LEO) satellites. These satellites orbit closer to Earth and move rapidly, requiring a network of many satellites to provide continuous coverage. They are used for global communication, especially in remote areas.
- **Geostationary Satellites:** Some satellite phones and direct broadcast satellite television use geostationary satellites. These satellites orbit at a much higher altitude (approximately 35,786 km) above the equator and move at the same speed as the Earth's rotation, appearing stationary from the ground. This allows a single satellite to cover a large geographical area and provides a continuous link for communication and broadcasting services.